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Methodology of Experimental Research of Damage to the Surface of Cylindrical Shells Under the Action of Impact by a Separate Mass

Anatoliy Dzyuba, Anatoliy Patsyuk

Oles Honchar Dnipro National University, Dnipro, Ukraine,
dzb@ua.fm, compumech@ua.fm

Abstract

A methodology for conducting systematic experimental studies of the bearing capacity of preloaded cylindrical shell models under the action of local impact loading of the surface by a separate mass has been developed. An author's installation for throwing solid bodies and their fragments has been created. The results of studies of the process of penetration of the surface of thin-walled structural elements by a separate mass and fragments of bodies for different parameters of their mass, speed and directions of action of individual fragments are presented.

Keywords: *impact load; cylindrical shell; surface damage; experimental research*

INTRODUCTION

Research into the survivability of shell elements of structures that are widely used in the creation of aircraft, protective structures and other mechanical engineering structures under extreme conditions is extremely important for a wide range of modern engineering objects.

There is a significant number of works devoted to the study of the behavior of shells under the influence of rigid external loads. In [1], a review of methods and approaches to the study of the processes of destruction of cylindrical shells under detonation loads is given. The loss of stability of shells under the influence of axial load at high temperatures was the subject of research in [2]. Thermomechanical processes in the shells of aircraft panels, caused by the impact of tire fragments, are studied in [3], and the static and dynamic effects of bird strikes on the glazing of cars and aircraft are studied in [4]. It should be noted that most of the known works consider only individual cases of extreme loads. A systematic study of the processes of behavior of shell structures with damage caused by local extreme loads and the identification of relevant patterns requires its solution.

Significant mathematical difficulties are also characteristic of the theoretical solution of problems of stability (destruction) of shells with holes and defects. Therefore, the most reliable and effective method for studying the bearing capacity of shells with various types of damage remains the experiment. Despite the wide range of research results on this problem, most works [5,6,7] present research data obtained for a small number of models of different sizes, materials and a small range of changes in the parameters of shell holes, their number, shape and location, which did not allow the authors to draw more general conclusions.

Full-scale experimental studies of the processes of destruction of real structures under the action of impact by a separated mass are one of the high-cost stages of ensuring the survivability of thin-walled structural elements, in particular when designing hulls and glazing of automobile vehicles, aircraft, etc. Therefore, the creation of a methodology for replacing full-scale tests of such structural elements with less costly studies on simple models in laboratory conditions is quite important in creating a wide range of real mechanical engineering objects.

This approach allows, with minimal costs, to vary the parameters of the studied process, to identify the most dangerous types, magnitudes and directions of extreme (destructive) external loads and to create appropriate safety measures. It should be noted that the application of finite element computer modeling by the methods of these processes also has significant difficulties due to the transience [8] of such processes.

Research methodology

To solve the specified problem, the paper proposes a research methodology and describes a laboratory complex that includes static and dynamic loading devices for experimental modeling of damage processes of preloaded (stretched or compressed) parts of the surface of shell structure models. The developed complex includes devices for static loading of cylindrical shell models for tension-compression, bending and torsion, as well as impact loading devices in the form of a device for throwing solid bodies and their fragments onto the surface of the object under study [9].

A test complex designed to study the behavior of both loaded and unloaded static shell structures under the action of local impact loading by extraneous mass and (or) debris fragments.

Conducting such experimental studies using the developed complex, in contrast to high-cost full-scale tests, provides the opportunity to change the shape, mass, speed, number of fragments (fragments), the direction of action of a high-speed body and the energy of contact interaction of the objects under study, etc., which allows obtaining a wide range of data for identifying the features and regularities of the impact process and assessing the residual bearing capacity (survivability) of models of damaged thin-walled shell structures.

The components of the test complex are made in the form of autonomous functionally complete blocks, which simplifies its configuration for conducting a wide range of experimental work. The complex consists of a stand for loading the structure with static forces, a device for throwing solid bodies (Fig. 1), speed recording equipment, a signal delay synchronization system, etc.

The device for throwing solid bodies consists (Fig. 1) of a cylindrical base (1) made of heat-resistant electrical insulating material, current conductors (2), foil that explodes (4), an upper cover (6) with a guide hole for throwing the body (5), a working chamber and a sealing gasket (4) and a diaphragm (7). The entire system is bolted to ensure the strength and reliability of the installation in the event of high pressure in its internal chamber.

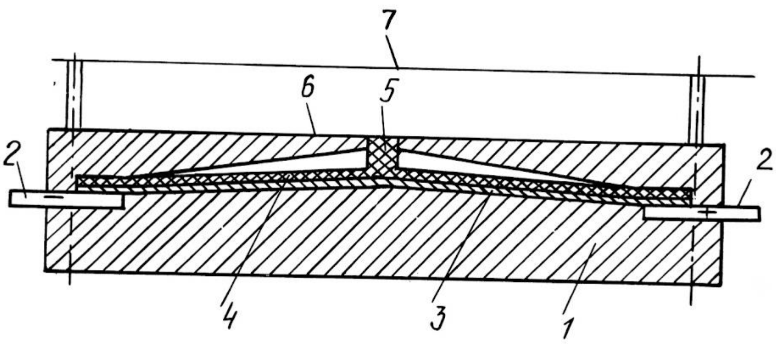

Fig.1. Schematic diagram of a device for throwing solids

The device for throwing solid objects is based on the electrical principle of detonating aluminum foil using a system of high-voltage capacitors. The aluminum foil is placed in a sealed chamber made of durable heat-resistant electrical insulating material.

In the flat part of the chamber, the foil is connected to a capacitor bank. In the middle of the flat part of the chamber there is an ellipsoidal recess with a longitudinal circular hole for throwing, where the body, or individual fragments, is placed to throw a given mass.

When voltage is applied to the current conductors from the capacitor bank, rapid combustion (detonation) of the foil in the working chamber occurs. As a result, the solid body is thrown out of the guide hole, and combustion products fly out behind it, which are delayed in the gap between the top cover and the thin diaphragm. After the diaphragm breaks, the thrown body crashes into a given place on the surface of the structure under study. The distance between the diaphragm and the object under study is preset, and the mass ejection speed can be changed by using special inserts to adjust the chamber volume, the capacitor charge level, etc.

For a detailed study of the destruction process, high-speed filming was used, and a technique was developed, as a result of which a need arose to reduce the effect of smoke from the combustion processes of aluminum foil in the chamber for throwing solid bodies in order to obtain a high-quality picture. For this, an easily destructive diaphragm was installed in front of the camera, which significantly improved the recording picture.

For a more accurate determination of the speed of the thrown solid bodies, a coordinate grid with a frequency of 2×10^{-2} *m* was installed along the flight path based on the results of high-speed filming

This method of determining the speed of solid bodies allows us to determine the speed of bodies before hitting the shell, as well as after leaving it, with sufficient reliability. This, in turn, allowed us to determine not only the kinetic energy of the bodies that were thrown, but also to estimate the amount of work done to destroy thin-walled structures.

The process of conducting the experiment is as follows. A chamber with a throwing body is directed at a certain part of the surface of the pre-loaded shell at a predetermined angle, and then the foil explodes in a sealed chamber by discharging capacitors pre-charged with the required energy, and the results of the impact load on the test object are recorded.

Research results

A wide range of experimental studies were conducted on the process of damage to the surface of cylindrical shell models under the action of local impact loading by a body of different mass, shape, number of fragments, their exit velocity, contact area and angle of entry of a solid body into the shell and their influence on the nature of deformation and the critical destructive force of loss of bearing capacity of preloaded shells.

In the process of developing and testing the methodology, cylindrical shell models were tested, which were made of sheet stainless steel by spot welding. Geometric dimensions of shell models: length L=0.05 m, radius R=0.025 m, thickness h=0.001 m. The bodies that were thrown were made of ebonite and had the shape of a cylinder with a flat or pointed front part. The effect of impact load on the residual strength of shells pre-loaded with axial tension was studied. The characteristic forms of damage of stretched metal shell models for the case of impact with a rigid cylindrical shell are shown in Fig. 2.

a) b) c) d)

Fig. 2 – Damage to the side surface of a pre-stretched shell after impact by a rigid of cylindrical body with a flat end and low velocity (a) and a conical front (b, c, d) and high velocity

From which it is seen that the damage to the side surface of the cylindrical shell differs significantly depending on the speed of the body and its shape.

The damage to the shell in Fig. 2,a corresponds to a lower speed and a flat front wall of the body being thrown. An increase in the speed of the body being thrown leads to an increase in residual deflections on the surface of the shell and more local deformation, and an increase in the mass of the body leads to the appearance of a through defect in the surface of the shell. A further increase in the speed of the body with its fixed mass and conical front part leads to a surface puncture in the form shown in Fig. 2,b, c, d.

These tests show that the magnitude of the tensile forces on the shell has practically no effect on the nature of its damage, i.e. it does not split into parts.

Large-scale experimental studies of the influence of various factors on the survivability of damaged shells are complicated by the obvious laboriousness and expense of conducting tests using metal samples. Therefore, a methodology for conducting such experimental studies on models of cylindrical shells made of special paper was additionally developed.

This material is characterized by high manufacturability and low cost of manufacturing nominally identical models. A comparative analysis of the test results obtained using models made of this material and stainless steel, as well as substantiation of the reliability of the test results of models made of paper are given in the article [10].

Fig. 3 shows damage patterns of cylindrical shell models compressed by a longitudinal force P*, where P* is the ratio of the critical force of loss of stability of the damaged shell to the critical force of an undamaged smooth cylindrical shell, E* is the relative energy of the impact mass.

a) $P^*=1.0$, $E^*=0$

b) $P^*=0.8$, $E^*=0.43$

c) $P^*=0.75$, $E^*=0.6$

d) $P^*=0.7$, $E^*=0.7$

e) $P^*=0.6$, $E^*=0.8$

f) $P^*=0.55$, $E^*=0.8$

g) $P^*=0.42$, $E^*=1.0$

h) $P^*=0.32$, $E^*=1.0$

Fig. 3 – Characteristic patterns of damage to the lateral surface of shells
compressed by longitudinal force (less than critical),
hit by a separate body and by the debris fragments

Fig. 3,a shows a classical picture of the loss of stability of a compressed cylindrical shell without the influence of impact load. Fig. 3,b,c,d shows the forms of the loss of stability of shells at the specified values of P* and E*. From which it can be seen that for a more loaded model, less energy of the destructive impact mass is required.

For comparison, Fig. 3,e,f, and Fig. 3,g,h show the pictures of the loss of stability of cylindrical shell models, which show that the action of several fragments, with a total mass equal to the mass of a single body, is more dangerous than the action of a single body.

Practical Importance

The presented methodology can serve as a basis for obtaining new knowledge about the processes of impact loading on the surface of thin-walled structures. The obtained actual experimental test data can be used to create a modern intelligent system for predicting critical loads and residual bearing capacity of power structures of modern mechanical engineering under conditions of extreme impact loads.

CONCLUSION

The methodology presented in the article provides an opportunity to conduct low-cost large-scale studies (to accumulate a wide range of sufficiently reliable experimental data) in order to identify features and regularities in the processes of destruction of preloaded power elements of structures under the action of high-speed impact loading, to identify the features of the impact process depending on the shape, mass, speed and number of thrown bodies, and to assess the bearing capacity (survivability) of models of preloaded shell structures. Such an approach allows to build a wide range of dependencies between the load parameters and stiffness characteristics of the structure and the mass and speed of individual bodies, the number of fragments, the angle of incidence and contact area and other parameters of the destruction process under impact loading, which can be useful when creating structures of new technology.

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REFERENCES

1. Malekan, Mohammad, Khosravi, Ali, Cimini,Carlos A. (2019) “Deformation and fracture of cylindrical tubes under detonation loading: A review of numerical and experimental analyses”International Journal of Pressure Vessels and Piping, Vol. 173, , P. 114-132, https://doi.org/10.1016/j.ijpvp.2019.05.003.
2. Liu, Fang, Niu, Tianye, Gong, Jian-Guo, Chen, Haofeng, Xuan, Fu-Zhen. (2023) ”Experimental and numerical investigations on buckling behaviours of axially compressed cylindrical–conical–cylindrical shells at elevated temperature’. Thin-Walled Structures, , Vol. 184, 110549, https://doi.org/10.1016/j.tws.2023.110549.
3. Wu X., Chen, Q, Zhao, B. et al. (2023) “Safety Assessment of Aircraft Panel under the Impact Load by Tire Fragment Based on Thermal–Mechanical Effect” Journal of Materi Eng and Perform No 32. P.1119–1132. https://doi.org/10.1007/s11665-022-07180-x ,
4. Rodichev, Y.M., Smetankina, N.V., Shupikov, O.M., Ugrimov, S.V. (2018) “Stress-strain Assessment for laminated aircraft cockpit windows at static and dynamic load” Strength of Materials. Vol. 50. No. 6. Springer, US. P. 868–873
5. Kamalarajah, R., Stoffberg, W., Bull, J. W., Chizari, M. (2015) “Stress Analysis of Uniform Circular Cylindrical Shells with Large Circular Holes” Proc.of The World Congress on Engineerig. London, U. K. P. 1169– 1172.
6. Kumar, V., Panda, S. K., Dwivedi, M., Mahmoud, S. R., & Balubaid, M. (2023) “Nonlinear Modal Responses of Damaged Shell Structures: Numerical Prediction and Experimental Validation. AIAA Journal, . Vol. 61(5). P. 2299–2308.
7. Stasiewics, P. (2013) “Analytical and Experimental studies of Stability of Cylindrical Shells with a Cut – Out”. Mechanics and Mechanical Engineering. No 2. P. 167–176.
8. Physics of high-speed processes / edited by N.A. Zlatin, Moscow: Mir, 1971. Vol. 2. 352 p.
9. Dzyuba, A.P., Patsyuk, A.G., Dzyuba, O.A. Patent No. 157830 Ukraine. “Method of throwing solid bodies” Application No. u2024 02870 dated 05/29/2024 publ. 11/27/2024. Bull. No. 48. https://sis.nipo.gov.ua/uk/search/detail/1828687/
10. Dziuba, A.P., Dziuba, P.A. (2024). “Experimental Studies on Stability of Longitudinally Compressed Cylindrical Shells at Accumulating Random Cuts-Cracks”. Int Appl Mech Vol.60. P.599-607 https://doi.org/10.1007/s10778-025-01312-1.